OS41B-1816

Eastward shift of the Walker Circulation under global warming and its relationship to ENSO variability

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Abstract

The global warming response of the Walker Circulation and the other zonal circulation cells (represented by the zonal stream function) is investigated in a CMIP5 multi-model ensemble (MMEns) under the RCP4.5 scenario. The changes in the mean state are presented as well as the changes in the modes of variability.

The mean zonal circulation weakens nearly everywhere along the equator. Over the Pacific Ocean the Walker cell also shows a significant eastward shift (Fig. 1). These changes in the mean circulation are very similar to the leading mode of interannual variability in the tropical zonal circulation cells, which is dominated by ENSO variability (Fig. 2a,b). During an El Nino event the circulation weakens and the rising branch over the Maritime Continent shifts to the east in comparison to neutral conditions (vice versa for a La Nina event). Two thirds of the global warming forced trend of the Walker cell can be explained by a long-term trend in this interannual variability pattern, i.e. a shift towards more El Nino-like conditions in the multi-model mean under global warming (Fig. 2c).

In interannual variability the zonal circulation exhibits an asymmetry between El Nino and La Nina events (not shown): El Nino anomalies are located more to the east compared to La Nina anomalies. Consistent with this asymmetry we find a shift to the east of the dominant mode of variability of zonal stream function under global warming (Fig. 3a,b). All these results vary among the individual models, but the MMEns of CMIP3 and CMIP5 show in nearly all aspects very similar results (Fig. 5), which underlines the robustness of these results.

The observed data (ERA Interim reanalysis) from 1979 to 2012 shows a westward shift and strengthening of the Walker Circulation (Fig. 4a,c). This is opposite to what the results in the CMIP models reveal. However, 75% of the trend of the Walker Cell can again be explained by a shift of the dominant mode of variability, but here towards more La Nina-like conditions (Fig. 4b). Thus long-term trends of the Walker cell seem to follow to a large part the pre-existing dominant mode of internal variability.

Eastward shift in the mean state

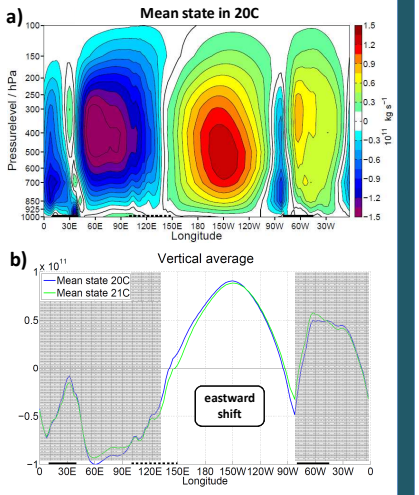

Figure 1: (a) Mean state of zonal stream function along the equator in CMIP5 MMEns over the period from 1950 to 1979 (20C), averaged from 5°S to 5°N; black bold lines at the bottom indicate the three continents Africa, Maritime Continent and South America, (b) vertical average of (a) in kg s^{-1} (blue line) and mean state over the period from 2070 to 2099 in kg s^{-1} (21C) (green line)

Model intercomparison

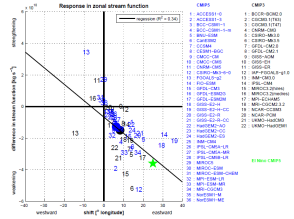

Figure 5: Response of zonal stream function under global warming in the individual models of the CMIP3 and CMIP5 data base, on the x-axis the shift of the western edge (zero line of stream function) of Walker cell, on the y-axis the trend of zonal stream function averaged over the box 120°E-180°, 700-300hPa.

Trend vs. El Nino

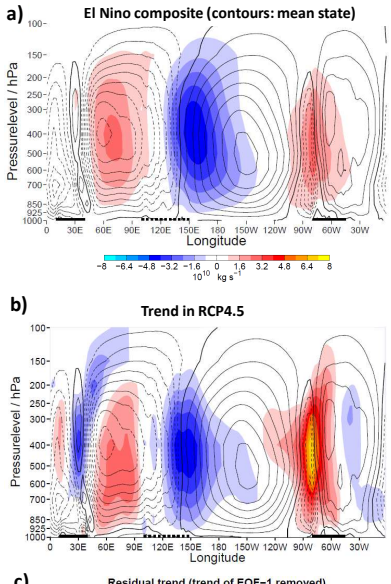

Figure 2: Shading: (a) Composites of zonal stream function in CMIP5 MMEns for Nino3.4 > 1 (El Nino) (Nino3.4: normalised SST index averaged over the box 170°W-120°W, 5°S-5°N), (b) linear trend of zonal stream function in CMIP5 MMEns in the period 1950 to 2099, (c) residual trend in zonal stream function in CMIP5 MMEns after removing the trend of EOF-1 in each model individually; contours in all figures: mean state from Figure 1a).

Eastward shift and trend in EOF-1

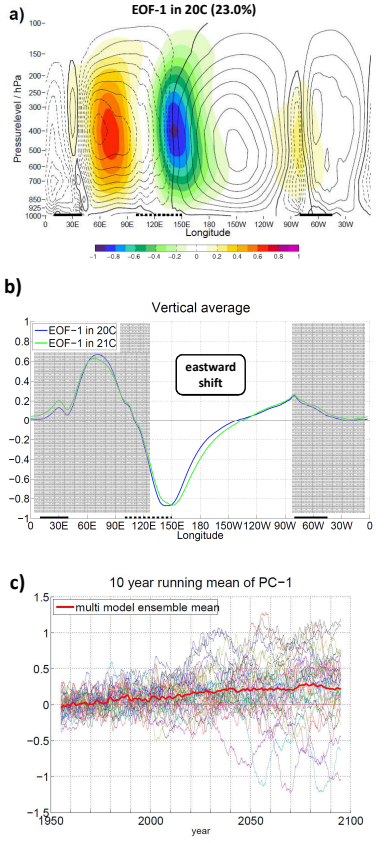

Figure 3: EOFs of zonal stream function in CMIP5 MMEns, shading: (a) EOF-1 in 20C, (b) EOF-1 in 21C, contours in both figures: mean state 20C from Fig. 1a, (c) 10 year running mean of PC-1 of zonal stream function in all individual CMIP5 models; the thick red line is the average of all 36 individual models.

Trend in ERA Interim

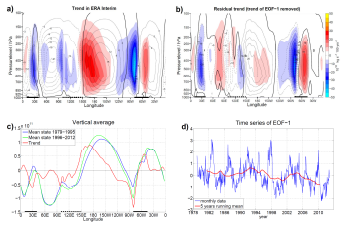

Figure 4: (a) trend in ERA Interim over the period 1979 to 2012, mean state of ERA Interim over this period as contours, (b) shading: the residual trend in ERA Interim after removing EOF-1, contours: the trend of (a), (c) same as Fig. 1b, but here for mean state (in kg s^{-1}) and trend (in kg s^{-1} (50yr)$^{-1}$) in ERA Interim, (d) time series of EOF-1 of zonal stream function in ERA Interim.

Conclusion:

- Walker Circulation shifts eastward in the mean state under global warming (GW) (Fig.1)
- Response to GW is similar to ENSO variability => El Nino-like trend (Fig. 2a,b and Fig. 3c)
- Trend in EOF-1 can explain 2/3 of the Walker Circulation changes (Fig. 2c)
- EOF-1 shifts eastward over the Pacific under GW (Fig. 3a,b)
- Most of the CMIP3 and CMIP5 models show an eastward shift of the Walker Circulation and an El Nino-like trend under GW (Fig. 5)
- ERA Interim shows a westward shift of the Walker Circulation (La Nina-like trend) (Fig. 4)

Reference:
Bayr, T., Dommenget, D., Martin, T. and Power, S. (2013), The Eastward Shift of the Walker Circulation in response to Global Warming and its relationship to ENSO variability, *submitted to Climate Dynamics.*

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